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(72) Inventors CARL HERTZ SAVIT
BEN BURT THIGPEN

(19)

(54) SEISMIC DETECTOR CONVEYANCES

(71) We, WESTERN GEOPHYSICAL COMPANY OF AMERICA, a corporation organised and existing under the laws of the State of Delaware, United States of America, having an office at 360 North Crescent Drive, Beverly Hills, California 90213, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention generally relates to seismic exploration and is particularly concerned with seismic detector conveyances.

According to the invention, there is provided a seismic detector conveyance having a plurality of individual, separately operable, seismic detector units spaced apart along a flexible structure which can be placed in a substantially flat condition and which constitutes a supporting structure for said detector units, wherein the flexible structure supports an electrical multi-conductor cable composed of pairs of conductors connected only to respective ones of a plurality of the units so that these plurality of units can be utilised simultaneously but with independent recording of their signals at a seismic recording station.

The term "detector unit" is to be construed herein as a seismic detection means which is independently operable and which may comprise a single seismic detector or an electrically interconnected array of detectors.

The conveyance may be designed as a seismic array or arrays for towing over the earth's surface. The earth may be covered with ice, snow, gravel, sand, brush, water, etc. Thus, when the terrain to be surveyed is covered with water, the detectors of the units may be hydrophones, while, in other cases, the detectors may be geophones. Combinations of the two types of detectors are also possible.

Such an array of detectors can be constructed to slide relatively easily over rough obstacles, possibly to be constrained to follow a substantially straight track behind a towing vehicle, to reduce the risk of becoming entangled with obstructions, to withstand severe abrasion, and to be substantially noiseless when under tow in water. Such a seismic detector conveyance for marine use preferably also has a low profile, i.e. a smooth surface configuration, to resist being moved by strong currents and waves.

Whenever a seismic detector conveyance is to be pulled over terrain, which could be either land or the bottom of a body of water, it is desirable for the seismic detector conveyance to maintain a relatively stable orientation with respect to the terrain. Thus, excessive rotation or twisting of such conveyances easily prevents, or at least impedes, the proper function of the individual detectors, because, upon a change of the orientation, they frequently come out of physical contact with the terrain. As a result, the quality of acoustic energy transfer from the terrain to the detector is impaired, with the result of unsatisfactory seismograms produced by the seismic recording system connected to the detectors.

Accordingly embodiments of seismic detector conveyances are proposed substantially to maintain physical contact, and therewith transfer of acoustic energy, between the seismic detector conveyance and the terrain over which such conveyance is being moved during operation. Embodiments are also proposed substantially to prevent the production of unsatisfactory seismograms, when optimum conditions for the transfer of acoustic energy are not fulfilled.

It will be apparent from the description hereinafter taken in conjunction with the

accompanying drawings, that a seismic detector conveyance is proposed that is relatively stable during tow over extended terrain surfaces which may be covered with sand, ice, snow, gravel, water, etc., including the bottom of a shallow body of water.

In an exemplary embodiment of the invention, the conveyance includes an elongate flexible structure carrying a plurality of seismic detectors. Each detector is positioned for seismic coupling, i.e. transfer of acoustic energy, with the surface of the terrain. The flexible structure is an elongate belt which has a width sufficient to prevent the belt from substantial rotating or twisting motion about its longitudinal axis during tow. Each detector may be accommodated in a housing having a base with a configuration such as to facilitate the movement of the housing over the surface of the terrain to be surveyed. If necessary, or desirable, each detector housing may be acoustically isolated from the belt. Arrangements may be provided to detect the existence of proper seismic coupling between the detector and the terrain and to automatically block the detector's output, should improper seismic coupling occur. The vehicle used when towing the seismic detector conveyance may be provided with surface-conditioning means to clear a path for the detector conveyance. Various beltings, i.e. belt materials, can be employed, such as those which are used, for example, in mechanical conveyor handling equipment. A multi-conductor cable forms an integral part with the elongate flexible supporting structure and interconnects the detectors with a signal utilization device, which is a seismic recording equipment.

In another exemplary embodiment when the seismic detector conveyance is to be used as an underwater seismic detector conveyance which is relatively stable during tow even over an irregular bottom, the elongate flexible structure supports a plurality of seismic detectors which may be hydrophones. More specifically, the flexible structure of the marine seismic conveyance is also a relatively thin, elongate, streamlined flexible belt having a lateral dimension sufficient to constrain the entire conveyance to remain substantially flat, and it has a specific weight great enough to cause it to lie firmly on the bottom of the body of water. In this case, the flexible supporting structure preferably includes at least two plies of belting. Hydrophones and a multi-conductor cable are sandwiched between the two plies of the belt.

In accordance with a feature common to most embodiments, for convenience in handling, the seismic detector conveyance is formed from sections which are mutually interconnected mechanically and electrically.

By providing a smooth configuration, the seismic detector conveyance can be towed continuously, without generation of towing noises such as would interfere with the reception of acoustic waves.

The flexible structure preferably has a thickness dimension which is relatively thin, either temporarily or permanently, in comparison to its breadth and length dimensions. Detectors will generally be supported by the flexible structure in a linear arrangement, and the dimension of the flexible structure in a direction normal to a line interconnecting adjacent detectors will preferably exceed the dimension of a detector, as measured in the same direction. Preferably, this breadth dimension of the flexible structure equals at least twice the dimension of the detectors.

It can be seen that, in several embodiments, the flexible structure may be defined as a strip of sheet material having the configuration of a band-shaped, elongate belt. Because of its relatively great length, mostly needed in the performance of seismic surveys, such a flexible structure is suitably subdivided into mutually detachable sections. When in use, the flexible structure will generally support and mechanically interconnect a plurality of detectors, and it also supports an electrical cable for connecting detectors to a seismic recording station.

In certain practical embodiments, each of a plurality of seismic detectors extends through a distinct opening through the flexible structure. An individual housing is provided for each detector, each housing being mounted to the flexible structure, and good results have been obtained when each of the housings is a solid body, except for a cavity receiving the detector, the weight of the housing, during operation, maintaining the housing in physical contact with a surface upon which it rests. Satisfactory transfer of acoustic energy is achieved when the detector closely fits into the cavity.

In one such embodiment, each of the housings is composed of two half shells, an area of the flexible structure being clamped between two shells. Moreover, a detector may be mounted to the flexible structure for power-controlled displacement in a direction substantially normal to the plane of the flexible structure, to assure physical contact with terrain surfaces, whereas acoustic decoupling from the flexible supporting structure is suitably achieved by arrangements for acoustically isolating the housing from the flexible structure. In one possible implementation, the arrangements include a flap cut out of

the flexible structure, except for a relatively narrow area by which the flap remains connected to the remainder of the belt, the housing being secured to the flap. Alternatively, the arrangements may include a flexible membrane, the housing being secured to a central area of the membrane whose periphery is secured to the rim of an opening in the flexible structure.

For operation in extremely cold zones of the world, a heater element may be mounted within the housing of a detector.

The conveyance may include switching circuits operable to disable a detector, unless the detector is in surface contact with terrain underneath it. To complete the conveyance for operation, there will be added a vehicle for towing the flexible structure, possibly combined with arrangements for at least partly clearing a path for the flexible structure.

Generally speaking, whenever intended for use in land seismic surveys, at least some of the detectors are geophones, while, for use in marine seismic surveys, hydrophones will be preferred. However, the use of both types of detectors combined in one conveyence is possible.

It will be apparent to the expert that a universally useful seismic detector conveyance will be obtained by the combination of geophones and hydrophones as detectors supported by the flexible structure.

For the specific purpose of marine seismic surveys, one embodiment has its flexible structure composed of at least two layers, of which one, during operation, constitutes an upper ply and another constitutes a lower ply. Then, the detectors are preferably mounted between plies of the flexible structure. Thus, the upper and lower plies may be spaced apart, one from the other, at those locations where the detectors, suitably hydrophones, are positioned. The electrical cable interconnecting the detectors with a seismic recorder may then also be located between plies of the flexible structure. Resistance to wear and tear will be increased by reinforcing, intermittent, lengths of plies at the locations of the detectors, and at the side of the flexible structure which, during operation, contacts the terrain underneath the flexible structure.

It was also recognized that the supporting structure for the detectors of an array, instead of permanently having the shape of a belt or similar structure, could include a deformable composition which only temporarily assumes a shape whose cross section resembles the cross section of a belt, i.e. a shape of a relatively great breadth as compared to its height or thickness. Thus, it was recognized that a free-flowing material, if properly constrained, would assume the desired configuration and operate similarly to a belt whenever it is supported by a terrain formation underneath it. Then, the interconnection between detector assemblies, of which each is constructed with the use of such free-flowing material, could be cables or any equivalent, as each assembly would temporarily, namely under operating conditions, perform the function of a relatively short length of belting material.

Thus, generally speaking, the flexible structure constituting a supporting structure for the detector units can be deformable so as to be capable of dimensional changes permitting it to temporarily assume a substantially flat configuration in sound-transmissive contact with the terrain.

In one such embodiment, the mass is formed by a pliable container enclosing material, e.g. upto four-fifths of its full capacity, capable of flowing freely due to its own weight and at least one detector is mounted adjacent the material. Frequently, the detector will be a geophone, though hydrophones may be used whenever desired. The free-flowing material may be granular or granulated material, such as lead shot or barium sulfate. Alternatively, the material may be mercury.

The container may be a bag of plastics sheet material, preferably with the detector mounted within the material contained in the bag, though, in some cases, the detector may be mounted upon the external surface of the container.

The detectors may be suspended in a pendulum-type fashion, thereby to maintain their orientation independently of any temporarily assumed configuration of the free-flowing material.

It will be seen that one may form a towable conveyance of detector assemblies comprising mutually interconnected detec-

It will be seen that one may form a towable conveyance of detector assemblies comprising mutually interconnected detector assemblies of the above-described character, with the individual detector assemblies being suitably inter-connected by individual cable sections. Then, the cable preferably extends through each of the containers.

For a better understanding of the invention and to show how the same may be made, by way of example, to the accarried into effect, reference will now be companying drawings, wherein:

Figure 1 is a schematic top view of a seismic detector conveyance suitable for operation on land and towed by a prime mover;

Figure 2 is a sectional view along line 2-2 of Figure 1, illustrating the coupling for the transfer of acoustic energy between a detector and underlying terrain;

Figure 3 illustrates, in top view, the area of joint between two adjacent sections of the detector conveyance of Figure 1;

Figure 4 is a top view of a portion of the conveyance of Figure 1;

Figures 5 and 6 are sectional views along lines 5-5 and 6-6 of Figures 4 and 5, respectively;

Figure 7 is a top view of a portion of a conveyance according to Figures 1 to 6 with the exception that a detector is mounted in a flap;

Figure 8 is a sectional view along line 8-8 of Figure 7;

Figure 9 is a top view of a portion of a conveyance according to Figures 1 to 6 with the exception that a detector is mounted on a flexible membrane;

Figure 10 is a sectional view along line 10-10 of Figure 9;

Figure 11 schematically illustrates a detector mounted for remote coupling control by a solenoid-operated actuator;

Figure 12 is a schematic illustration of an arrangement for monitoring the existence of coupling and the orientation of the housing of a detector;

Figure 13 is an electrical circuit diagram of the circuit used in the arrangement of Figure 12;

Figure 14 is a schematic illustration of a marine seismic detector conveyance, equipped with hydrophones, as towed by a shallow-water vessel;

Figure 15 is a top view of a portion of a section of the conveyence of Figure 14;

Figure 16 is a sectional view along line 16-16 of Figure 15, illustrating a hydrophone mounted between the two plies of the belt-shaped flexible element;

Figure 17 is a top view of the hydrophone of Figure 16, as seen with most of the upper ply of the flexible element removed;

Figure 18 is a perspective view of a mounting plate for a hydrophone; and

Figure 19 illustrates, in a perspective view, the area of interconnection between two sections of the conveyance and a reinforced section of the belt forming the flexible element in the region of the hydrophone.

Referring to the embodiment of the invention illustrated in Figures 1 to 6, there is shown in Figure 1 a seismic detector conveyance 10 as it is towed over the earth's surface by a suitable prime mover 14 by means of a tow line 16 attached to a hitch 18. A suitable surface-conditioning equipment 20, such as one operating in similarity with a snowplow, may be employed to clear a path for the oncoming conveyance 10. In this embodiment, the conveyance 10 is very long, say several thousand feet, so it is conveniently formed from individual conveyance sections 21, coupled together by suitable coupling elements 22, Figure 3. Of course, the conveyance need not be sectionalized and may be continuous. Also, with the use of coupling elements 22, should a portion of the conveyance 10 be ruptured, repair in the field may be easily accomplished.

The flexible supporting element 30 of the conveyance 10 is made of a substantially flat material which is relatively thin. The essentially band-shaped belt thus forming the element 30 extends sufficiently in a lateral direction to prevent, or at least drastically reduce, the possibility of rotating or twisting motion of the entire assembly about its longitudinal axis 11. Materials which are especially suitable for the flexible supporting element, called the belt 30, include fabrics, rubber, plastics material, leather and combinations thereof. Conventional conveyor belting material has been found suitable. Typically, such belt materials are composed of plies of cotton duck, impregnated with a slow-aging rubber compound. As mentioned above, belt 30 can be composed of belt sections 21 having their adjacent ends jointed together either by cementing or connected together by the coupling elements 22, Figure 3.

The selection for a material for the belt 30 is not limited to any particular flexible sheet material, as long as it is sufficiently flexible, can be placed in a substantially flat condition, and strong to withstand the environmental conditions including extremely high and low temperatures, and the abrasiveness of the earth's top layer.

The main function of belt 30 is to serve as a stable, permanently properly oriented, towable common mechanical support element of the conveyance of suitably spaced-apart detectors 32 accommodated in housings 40, as shown in Figure 1, with the details of the housings 40 and the detectors 32 being illustrated in Figure 5. The use of a common mechanical support eliminates the need for direct manual labour and the possibility of human error in spacing the detectors. The seismic detectors 32 housed in or carried by belt 30, for example in the manner shown in Figure 5, can be of any conventional design. Land seismic detectors, as used in the embodiment of Figures 1 through 6, are commonly referred to as geophones. Each geophone includes a coil assembly (not shown) which is movable relative to a magnetic structure supported by the geophone housing. Motion of the coil assembly generates electrical signals across the geophone's output terminals 34, 35. Terminals 34, 35 are electrically coupled by wires 36, 37, respectively, to a signal channel, such as a specific pair of a plurality of pairs of conductors of a multiconductor cable 38. Cable 38 channels the output

signals from all of the geophones 32 to a utilization device 39 which typically includes a seismographic recorder.

Geophones 32 are typically grouped in detector arrays in a conventional manner. A detector array can extend over a portion or an entire conveyance section 21. On the other hand, a detector array can extend over two or more such sections, as will be apparent to those skilled in the art. Thus, for simplicity of the drawings, each illustrated geophone 32 may be interpreted to represent a cluster of geophones forming a detector array. The formation of each array and the type of detectors employed will depend on the selected, conventional seismic exploration technique, for example single-fold reflection, common-depth-point reflection, refraction profiling, etc. Accordingly, the term "land seismic exploration" or its equivalents, whenever used herein, is intended to encompass all such land seismic prospecting or surveying techniques. Also, the scope of the term "seismic detector" is not limited to any particular type of detector and may include detectors of the dynamic, variable-reluctance, solid state, pressure-responsive, etc., type. All these types of detectors are capable of converting seismic, i.e. acoustic, energy into electrical energy when the detectors are seismically coupled to the ground, as illustrated in Figure 2, where a housing 40 for a detector is shown in physical contact with the surface of uneven terrain 12. The generated electrical signals are conventionally amplified, recorded, combined and corrected, as may be necessary or desirable, by the utilization device 39.

An important advantage of this embodiment is derived from the fact that the flat flexible supporting element, namely belt 30, allows the use of relatively inexpensive so-called "vertical" geophones which are adapted to vibrate along an axis perpendicular to the direction of tow.

To provide good seismic coupling between each geophone 32 and ground 12, each of the geophones is snugly fitted inside its housing 40, the housing having an upper half section 42 and a lower half section 44, as illustrated in Figures 5 and 6. The lower half section 44 has an outer surface defining a flat central circular area 46, and an upwardly extending inclined or curved surface 48. The flat surface 46 is provided to achieve optimum seismic coupling between housing 40 and ground 12. The shape of surface 48 is selected to allow housing 40 to ride smoothly over any terrain, even over an irregular land surface, without snagging. Extending from the upper surface 50 of the lower half section 44 is an outwardly projecting annular shoulder 52, with a central, cylindrical cavity 51 formed internally of the shoulder 52. Cavity 51 finds its mating opposite cavity 49 in the upper half housing 42 and shoulder 52 finds a mating shoulder 52′. The height of each shoulders 52 and 52′ is substantially equal to one-half the thickness of belt 30 to allow the belt to become sandwiched, and thus clamped, between the two half housings 42 and 44. The inner diameters of cavities 49 and 51 are only slightly larger than the outer diameter of the geophone's casing to allow a close fit between the geophone 32 and housing 40. The outer diameter of shoulders 52 and 52′ is slightly smaller than the inner diameter of an opening 56 in belt 30, into which opening the shoulders extend upon assembly, as shown in Figure 5. A diametrically extending groove 58 in shoulder 52 allows terminal wires 36, 37 to pass therethrough.

The upper half housing 42 has an aerodynamically shaped external surface 60 to minimize wind resistance and, hence, wind-generated noise in the geophone 32. A plurality of bolts 62, symmetrically positioned along a circle, extend through a plurality of correspondingly positioned bores 63 in the belt 30. Thus, the bolts 62 detachably clamp the two half housings, or half shells, 42, 44 together and to the belt 30.

The multiconductor cable 38 is suitably secured to the upper surface of belt 30 by means of staples 64. Alternatively, it can be molded within the belting material, if desired. Cable 38 is typically formed of sections which are suitably interconnected by conventional multiconductor plugs (not shown).

After the sections 21, if sections are used, are coupled together to form a continuous belt 30 and the multiconductor cable sections are also interconnected, the belt 30 is ready to be towed by the prime mover 14. In areas having very irregular terrain, it is advantageous to employ the surface-conditioning equipment 20 which will even out some of the irregularities. The center of gravity of the belt's mass is very close to the earth's surface. Each of the housings 40, by virtue of its weight and solid construction, is maintained in good seismic coupling with the earth. If necessary, the lower half housings 44 can additionally be weighted to ensure maximum coupling with the ground. Also, since the belt 30 is flat, flexible and substantially wider than a housing 40, it will not exhibit any tendency to twist relative to its longitudinal axis 11. The dynamic, i.e. streamlined, shaping of housings 40 assures that they will not snag against objects extending from the earth's surface.

After belt 30 is towed to a desired seismic station, a shot hole is drilled in the ground and a suitable seismic charge placed in the hole. The charge is detonated to produce a downwardly directed seismic wave whose reflections from the underlying layers of the earth are detected by detectors 32. Each pair of conductors in the multi-conductor cable 38 may be connected to a separate channel in the recorder of utilization device 39 to obtain a record of a seismic signal or trace, i.e. sequence of such records of signals.

After recording of the seismic signal, another shot hole is drilled forward of the previous shot hole with the prime mover 14 moving the conveyance 10 to a new location for detecting another, similarly produced seismic signal.

It will be appreciated that seismic signal energy need not be derived from an explosion, but can be obtained from a gas-operated surface energy source or any other type of source. In an integrated system, the energy source may be mounted on the prime mover 14 which may be a wheel-mounted, or track mounted, vehicle.

Under certain operating and/or environmental conditions, vibrations of belt 30 can be undesirably transferred to the housings 40 of the detectors. To prevent this, as shown in Figures 7 and 8, each housing 40 may be mounted on a tongue or flap 70 which is cut out from the belting material, by providing the essentially circular cutout area 72. When the flap 70 extends over a depression 73 in the ground, it will be free to fall inside the depression to allow the detector housing 40 to seismically couple with the ground. The flap 70 acoustically isolates the housing 40 from the remainder of the belt, since the cutout portion 72 reduces the connection to the belt itself to a relatively narrow strip 74.

In a further modification of the embodiment of Figures 1 to 6, illustrated in Figures 9 and 10, the housing 40 is shown mounted on a flexible membrane 80 in a manner similar to the mounting of the housing 40 to the belt 30. The membrane 80 itself is secured to the rim of an opening in the belting by any suitable means, such as bolts 82. In practice, the relatively flexible membrane 80 will not transmit vibratory energy imparted to the belt 30, thereby isolating the housing 40 from vibrations of the belt. Membrane 80 also allows the housing 40 to move vertically up or down relative to the lateral plane of belt 30, thereby improving the seismic coupling for transfer of acoustic energy between housing 40 and the underlying terrain.

In the embodiment shown in Figure 11, one of the housings 40 for a detector is mounted at the bottom end of an armature 90 forming the core of a solenoid assembly 92 including a casing 91, whose coil 94 can be energized by connection to a source of current through a pair of wires 96 extending from the multiconductor cable 38. Solenoid assembly 92 is supported by a structure 97 on which is also mounted a spring 98 for normally maintaining the housing 40 in an up position, i.e. away from the terrain 12. Upon energization of coil 94, the armature 90 is caused to move downwardly to thereby establish firm coupling between housing 40 and the terrain. Since coupling between armature 90 and the casing 91 of solenoid 92 is thus relatively loose, any existing vibrations in the belt 30 will be greatly attenuated when transmitted to the housing 40.

An additional advantage obtained from the embodiment shown in Figure 11 is that the coupling of the detector with the underlying ground can be remotely controlled by energization of coil 94 and the force of such coupling can thus readily be varied.

For use in arctic regions where the ground is frozen or covered with snow and ice, housing 40 may be provided with a small electric heater 100, schematically illustrated in Figure 12, energized by power derived from the multiconductor cable 38. To achieve maximum coupling, the casing 40 is "welded" by virtue of being frozen onto the snow or ice. This is accomplished by first melting some of the immediately adjacent surface ice, whereupon the heater 100 is deenergized and allowed to sufficiently cool down, so that the melted snow refreezes to weld the housing 40 to the ground.

The outputs from the detectors in each array are typically combined together. If in such combination of outputs there is included the output of a detector whose housing is improperly coupled to the ground, the combined output from the array may be significantly degraded, especially if several improperly coupled housings form part of such a single array. To detect whether the housing 40 is contacting the ground, there may be provided a normally closed contact switch 102, schematically illustrated in Figures 12 and 13, as it has normally interconnected terminals 104 and 106. Upon contacting ground, contact switch 102 interrupts the connection between terminals 104 and 106, thereby removing a normally existing short circuit 107 from the coil 108 of the detector. Thus, only when housing 40 is properly coupled to the ground, a signal induced in coil 108 will be transmitted to the output leads 36, 37 of the detector.

As shown in Figure 13, housing 40 may also be provided with a tilt switch which may be a normally open mercury switch 112 having terminals 113 and 114. The open

switch 112 breaks the short circuit 115 across coil 108. If housing 40 tilts relative to the vertical 116, shown in Figure 12, by an angle which exceeds the allowed tilt angle for the particular detector employed, the mercury pool 120 will cause terminals 113 and 114 to become interconnected, thereby to short circuit coil 108 and prevent coil 108 from contributing an output signal through its output leads 36, 37.

With reference to Figures 14 to 19, illustrating a further embodiment which is particularly useful for seismic prospecting in shallow waters, there is shown in Figure 14 a seismic detector conveyance 120 supporting a plurality of seismic detectors, preferably hydrophones 122. The conveyance, after having been pulled, rests upon the bottom 124 of a body of water, as it is towed by a shallow-water vessel 126. Vessel 126 houses a reel 128 for storing the conveyance 120, when not in use. A multi-conductor cable 130 interconnects hydrophones 122 with a signal utilization device, actually seismic recording equipment 132, on vessel 126. A source of acoustic energy 134 is also towed in the water beneath vessel 126. Reflected seismic waves are sensed by hydrophones 122 and are converted into electrical signals which are transmitted to the recording equipment 132 by cable 130 for recordation, for example on magnetic tape.

Referring specifically to Figures 15 to 19, the seismic conveyance of this embodiment includes a belt 136 on which the detectors, such as hydrophones 122, are mounted by means of a mounting plate 138 (Figure 18) having tabs 140. Plate 138 is secured to belt 136 by bolts 142 passing through holes 144. Tabs 140 are bent around the body of a detector 122 which is firmly secured in place by straps 146. A "pigtail", i.e. short lead-in cable 148, interconnects each detector 122 with cable 130 at a takeout 150, such takeouts being provided at intervals along cable 130.

As best illustrated in Figure 16, and also in Figure 19, the flexible element, belt 136 of this embodiment, is composed of at least two plies, an upper ply 152 and a lower ply 154, between which, in areas where the plies are separated, is sandwiched one of the hydrophones 122 and its mountings. Preferably, the cable 130 also extends between plies of the belt. The detectors are thus protected from damage while being towed over any terrain, such as bottom 124 (Figure 14) of a body of water. Plies 152 and 154 are suitably joined one to another by staples 156 into a single unit, except for the afore-mentioned areas, to form the complete belt 136.

Since the flexible belt 136 will normally stretch somewhat under tow, means may be provided to introduce slack in cable 130.

Inasmuch as the entire detector conveyance 120 may be up to one and one-half miles long, it was found convenient to divide it into sections. Mechanical and electrical connections are then provided at the ends of each section, as shown in Figure 19. For example, sections 160 and 162 are each provided with two metallic connecting lugs 164 and 166, respectively. Each lug is bolted to the opposite lug by a bolt 168. Lugs 164 and 166 are bolted to their respective sections by bolts 170 and 172. The sections of cable 130 can be joined between sections 160 and 162 by means of a conventional waterproof connector 174.

In many areas, the sea floor, as well as any terrain, is irregular and abrasive. It, therefore, becomes desirable to reinforce the bottom part of belt 136, particularly in the areas where the detectors, such as hydrophones 122, are mounted. Accordingly, an additional ply 176, shown in Figure 19, may be added beneath the portion of belt 136 at the locations where detectors are mounted.

It will be seen that, in the embodiment of Figures 14 to 19, the belt 136 also constitutes a flat, thin, flexible supporting element which extends sufficiently in a lateral direction, so that rotating or twisting motion of the conveyance 120 about its longitudinal axis is greatly limited, if not prevented. A material which is especially suitable for belt 136 is preferably made from rubber, polyurethane, or a combination thereof with a rubber fabric. In this embodiment, too, ordinary conveyor belt material is very suitable. Typically, such conveyor belts are composed of several plies of cotton duck impregnated with a slow-aging rubber or neoprene compound. The advantage gained by the use of conveyor belt material is that it is specially designed to withstand severe abrasion when in contact with sharp objects, such as those that could be found on the ocean floor.

The seismic detector conveyance 120 has sufficient density to cause it to always rest upon the bottom 124 of a body of water, thereby avoiding noise from wind and wave action. The smooth surface configuration, without abrupt proturberances, of the conveyance permits it to be pulled over irregular terrain, particularly the bottom of a body of water, without generating excessive noise due to tow motion.

The detectors 122, e.g. geophones or hydrophones, are typically grouped into arrays, each containing one individual detector, or more, in similarity with the detectors of the embodiments of Figures 1 to 6. For example, section 162 of the complete conveyance 120 might contain several hydrophones forming a single array. On the

other hand, a single array can extend over two or more sections 160 and 162, as will be apparent to those skilled in the art. The formation of each array and the type of detectors, i.e. geophones or hydrophones, employed will be selected depending upon the intended use and the preferred, conventional seismic exploration technique, for example single-fold reflection, common-depth-point reflection, refraction profiling, etc. The term "seismic detector" is not limited to any particular type and includes geophones and hydrophones of the variable reluctance, or solid state, types. All such detectors are capable to convert seismic, i.e. acoustic, energy into electrical energy. The electrical signals so generated are conventionally amplified, filtered, recorded, combined and corrected, as may be necessary and desirable, by the utilization device 39 or 132.

While this invention has been discussed with respect to land and marine surveying at sea, it is to be understood that the seismic detector conveyance of the embodiment of Figures 14 to 19 can be used in any body of water and can be towed by various prime movers, such as surface boats, submarines, submarine tractors, or even manpower.

An important advantage of the seismic detector conveyance in accordance with the embodiments of Figures 1 to 19 is that conveyor belting is an inexpensive material and readily obtainable anywhere, including all important seaports. Thus, the conveyance can be repaired in the field without need for special tools and materials.

Since the embodiment for marine use has a broad, low profile, bottom sea currents and wave action in the surf will not easily shift it from its desired position. Not only is it now possible to use this conveyance to extend a marine survey to shallow water depths, but it is also possible to continue the survey with the same conveyance through the surf line into a land environment.

As will also be apparent from the foregoing description, the embodiments described eliminate most of the manual handling of the detectors in seismographic exploration and allow the detectors to be automatically conveyed over practically any terrain to be surveyed, while maintaining their desired mutual spacing for optimum detector array output. The use of a relatively wide, flexible element, such as the belt 30 or 136 as a support and spacer for the detectors 32 and 122, respectively, constrains the detectors to remain in their preferred orientation with respect to the vertical, both during tow and when positioned for seismic detection. With these embodiments the need for relatively expensive, gimbal-mounted detectors such as were required in known equipment, is eliminated.

Moreover, the weighting of the belt itself adds further coupling power to the detectors, be it in the housings 40 or as mounted between two plies of a belt 136, while the low surface relief, i.e. the smooth surface, of the belt considerably reduces extraneous noises, such as have been experienced by known detector conveyances which were deletoriously affected by wind noise and fluttering of the element interconnecting the detectors.

Even though the manner of generating seismic energy is described herein in connection with explosives, nonexplosive seismic energy sources can be used, as well. Thus, this invention is not limited to the type of seismic energy source employed. For example, nonexplosive seismic energy sources which are commercially available may be mounted on track-type vehicles which can also house the seismic recording equipment 39. The carrier of the seismic energy source could also be used to tow the seismic detector conveyance.

Moreover, when used in land seismic exploration, a greater surface area can now be seismically surveyed in a given time, since the hand-lifting and hand-reemplacement of the detectors are no longer necessary. A precision navigation positioning system may be used on the tow vehicle for directing the vehicle and permanently recording the geographic locations of the seismic detector conveyance and of the seismic energy source at all times, while the seismic prospecting is being conducted.

WHAT WE CLAIM IS:—

1. A seismic detector conveyance having a plurality of individual, separately operable, seismic detector units spaced apart along a flexible structure which can be placed in a substantially flat condition and which constitutes a supporting structure for said detector units, wherein the flexible structure supports an electrical multiconductor cable composed of pairs of conductors connected only to respective ones of a plurality of the units so that these plurality of units can be utilised simultaneously but with independent recording of their signals at a seismic recording station.

2. A conveyance according to claim 1, wherein the flexible structure has a configuration in which it has opposed major surfaces the distance between which is small in comparison to the dimensions of the structure taken at right angles to said distance.

3. A conveyance according to claim 1 or claim 2, wherein the dimension of the flexible structure in a direction normal to a line interconnecting adjacent detectors of

the units exceeds the dimension of these detectors, as measured in the same direction.

4. A conveyance according to claim 3, wherein the said dimension of the flexible structure equals at least twice the said dimension of those detectors.

5. A conveyance according to claim 2 or to claim 3 or 4 when appended to claim 2, wherein the flexible structure is of elongate form.

6. A conveyance according to any one of the preceding claims, wherein the flexible structure comprises mutually detachable flexible sections.

7. A conveyance according to any one of the preceding claims, wherein the detectors of the units extend through openings through the flexible structure.

8. A conveyance according to any one of the preceding claims, wherein each detector unit has a detector or detectors with its or their own housing or housings and the housings being mounted to the flexible structure.

9. A conveyance according to claim 8, wherein each housing is a solid body, except for a cavity containing its detector, the weight of the housing being such as, during operation in a medium of predetermined specific gravity, to maintain the housing in physical contact with a surface upon which it rests.

10. A conveyance according to claim 9, wherein the detector closely fits into the cavity.

11. A conveyance according to claim 8, claim 9 or claim 10, wherein each of the housings is composed of two half shells, an area of the flexible structure being clamped between the two shells.

12. A conveyance according to claim 8, claim 9 or claim 10, wherein one detector is mounted to the flexible structure for power-controlled displacement in a direction substantially normal to the plane parallel to which the flexible structure can be placed in a substantially flat condition.

13. A conveyance according to any one of claims 8 to 12, and comprising means for acoustically isolating each housing from the flexible structure.

14. A conveyance according to claim 13, wherein said means comprise a flap having a form as if cut out of the flexible structure, except for a relatively narrow area by which the flap remains connected to the remainder of the structure, the housing being secured to the flap.

15. A conveyance according to claim 14, wherein said means comprise a flexible membrane, the housing being secured to a central area of the membrane and the periphery of the membrane being secured to the rim of an opening in the flexible structure.

16. A conveyance according to any one of claims 8 to 15, and comprising a heater element within at least one housing.

17. A conveyance according to any one of the preceding claims, and comprising a switching circuit operable to disable each detector unit, unless that detector unit is in surface contact with terrain underneath it.

18. A conveyance according to any one of the preceding claims, in combination with a vehicle for towing the flexible structure.

19. A conveyance according to claim 18, and comprising means for at least partly clearing a path for the flexible structure.

20. A conveyance according to any one of the preceding claims, wherein at least one of the detector units comprises a geophone.

21. A conveyance according to any one of claims 1 to 6, wherein the flexible structure is composed of at least two layers, arranged so that, during operation, one can constitute an upper ply and another a lower ply.

22. A conveyance according to claim 21, wherein each detector unit is mounted between plies of the flexible structure.

23. A conveyance according to claim 22, wherein the upper and lower plies are spaced apart at those locations where the detector units are positioned.

24. A conveyance according to any one of claims 21 to 23, wherein the electrical cable for interconnecting the detector units with a seismic recorder is located between plies of the flexible structure.

25. A conveyance according to any one of claims 21 to 24, and comprising reinforcing, intermittent, lengths of plies at the locations at which the or each detector of each detector unit is joined to the structure and at the side of the flexible structure which can be caused, during operation, to contact the terrain underneath the flexible structure.

26. A conveyance according to any one of claims 21 to 25, wherein at least one of the detector units comprises a hydrophone.

27. A conveyance according to any one of the preceding claims, wherein the detector units include geophones and hydrophones supported by the flexible structure.

28. A conveyance according to any one of the preceding claims, wherein said flexible structure constituting a supporting structure for the detector units is deformable such as to be capable of dimensional changes permitting it to temporarily assume a substantially flat configuration.

29. A conveyance according to claim 28, wherein the structure comprises a mass of deformable material in sound-transmissive contact with a detector of a

detector unit, the material being capable of conforming its shape to that of the terrain upon which it rests.

30. A conveyance according to claim 29, wherein the mass is formed by a pliable container enclosing material capable of flowing freely due to its own weight and at least one detector is mounted adjacent the material.

31. A conveyance according to claim 30, wherein the detector adjacent the material is a geophone.

32. A conveyance according to claim 30 or claim 31, wherein the material is a granular material.

33. A conveyance according to claim 32, wherein the material is lead shot.

34. A conveyance according to claim 32, wherein the material is barium sulfate.

35. A conveyance according to claim 30 or claim 31, wherein the material is mercury.

36. A conveyance according to any one of claims 30 to 35, wherein the container is a bag of plastics sheet material.

37. A conveyance according to any one of claims 30 to 36, wherein the detector is mounted within the material.

38. A conveyance according to any one of claims 30 to 36, wherein the detector is mounted upon the external surface of the container.

39. A conveyance according to any one of claims 30 to 38, wherein the detector adjacent the material is suspended in a pendulum-type fashion, thereby to maintain its orientation independently of the arrangement of the free-flowing material.

40. A conveyance according to any one of claims 30 to 39, wherein the container is filled with the material to about four-fifths of its full capacity.

41. A seismic detector conveyance substantially as hereinbefore described with reference to Figures 1 to 6 or those figures as modified by Figures 7 and 8 or by Figures 9 and 10 or by Figure 11 and/or by Figures 12 and 13, or with reference to Figures 14 to 19 of the accompanying drawings.

HASELTINE LAKE & CO.,
Chartered Patent Agents,

Hazlitt House,
28 Southampton Buildings,
Chancery Lane,
London, WC2A 1AT,
— and —
9 Park Square,
Leeds, LS1 2LH,
— and —
Temple Gate House,
Temple Gate,
Bristol, BS1 6PT.

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1385971 COMPLETE SPECIFICATION

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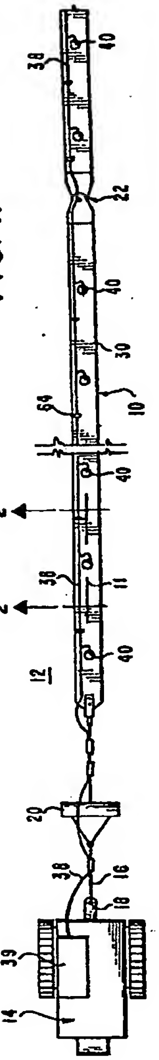

FIG. 1.

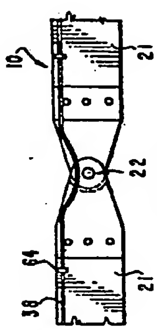

FIG. 3.

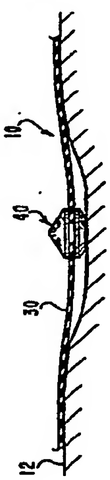

FIG. 2.

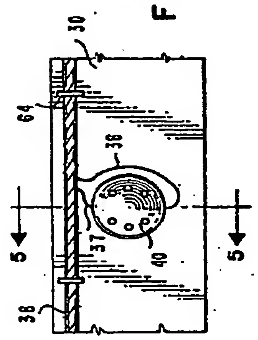

FIG. 4.

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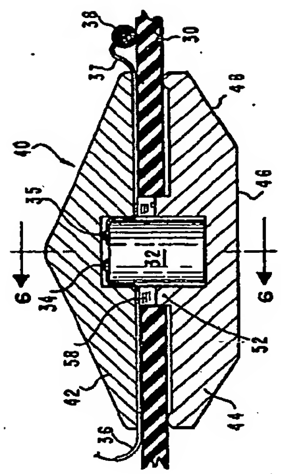

FIG.5.

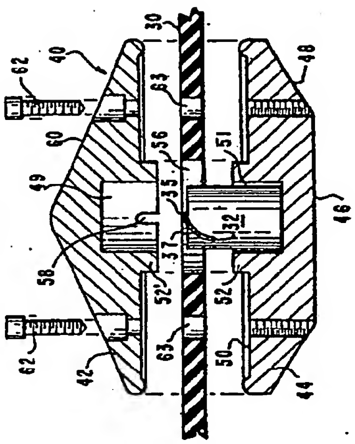

FIG. 6.

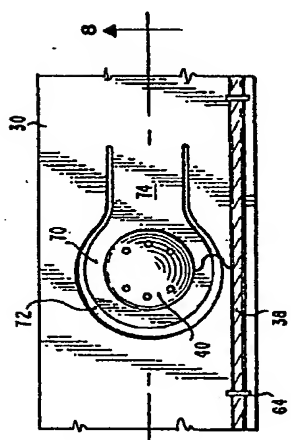

FIG. 7.

FIG. 8.

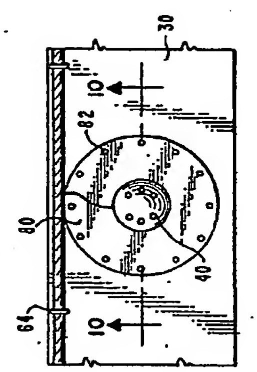

FIG. 9.

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FIG. 10.

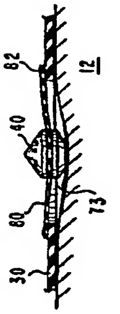


FIG. 11.

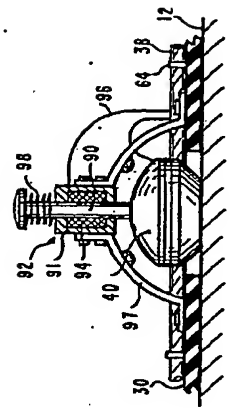


FIG. 12.

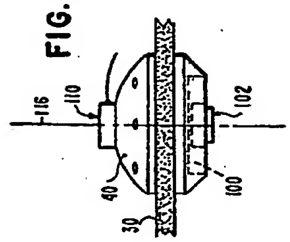


FIG. 13.

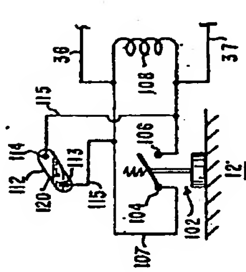
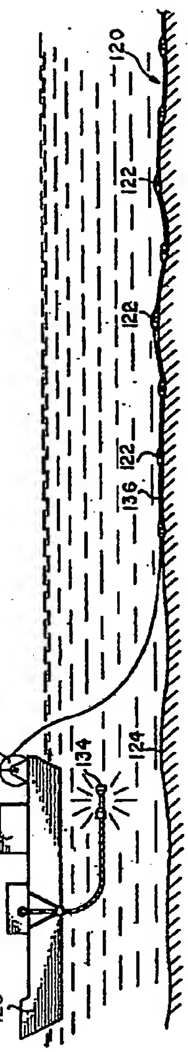


FIG. 14



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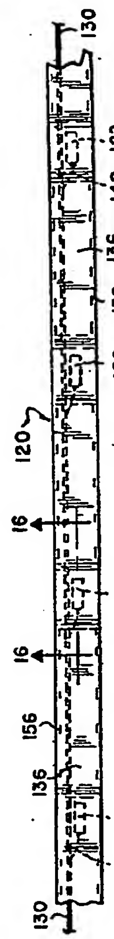

FIG.15

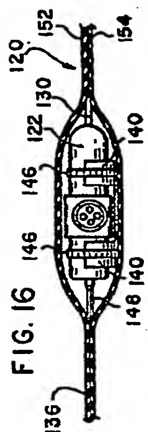

FIG.16

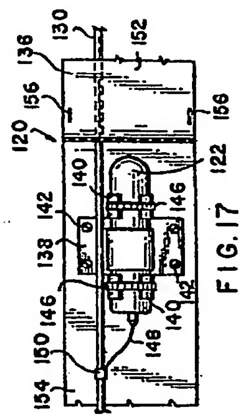

FIG.17

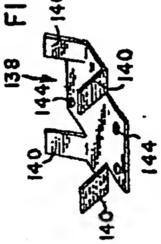

FIG.18

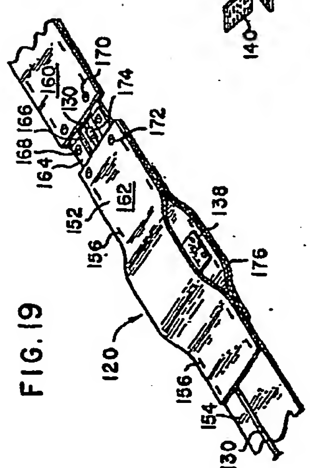

FIG.19